Chapter 10

Raw Grinding Systems

Raw Grinding Systems

1. PURPOSE OF RAW GRINDING

The raw grinding is the size reduction stage for raw material between crushing and burning process (figure 1) and has to fulfill the requirements:

- Produce a raw meal fineness (particle size and particle size distribution) adequate for the production of the required clinker quality
- Provide the proper raw mix by proportioning the components in the correct percentages
- Mixing the components
- Drying of the raw material to enable a good handling of the raw meal

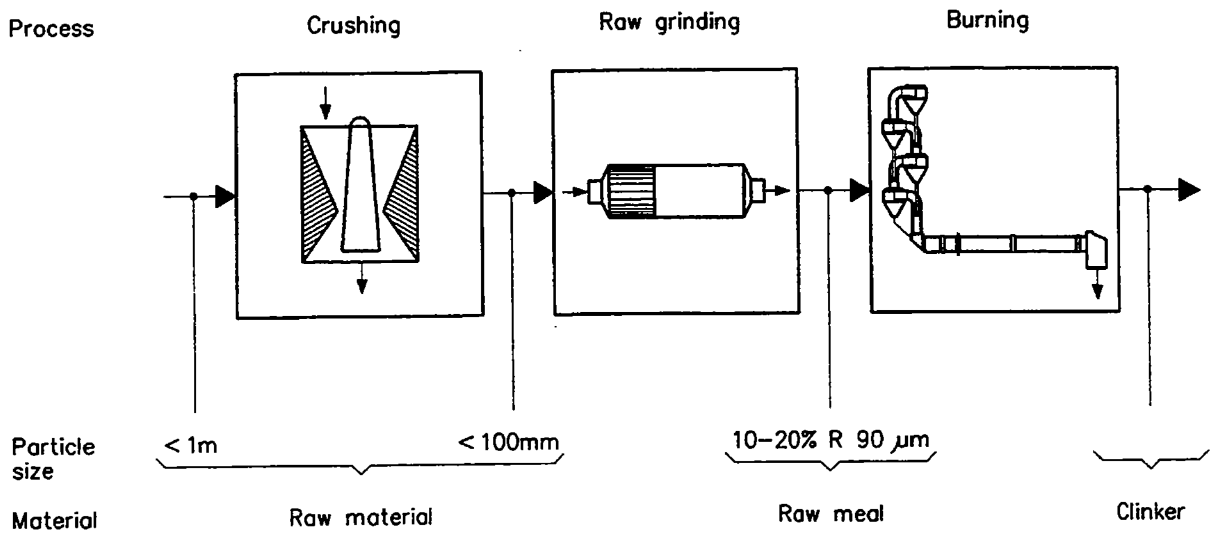
The raw grinding stage cannot homogenize the raw meal due to the short retention time in this process.

The raw grinding can be divided in

- Dry grinding process
- Wet grinding process

All new installations are, with few exceptions, dry grinding processes.

Figure 1 Purpose of Raw Grinding



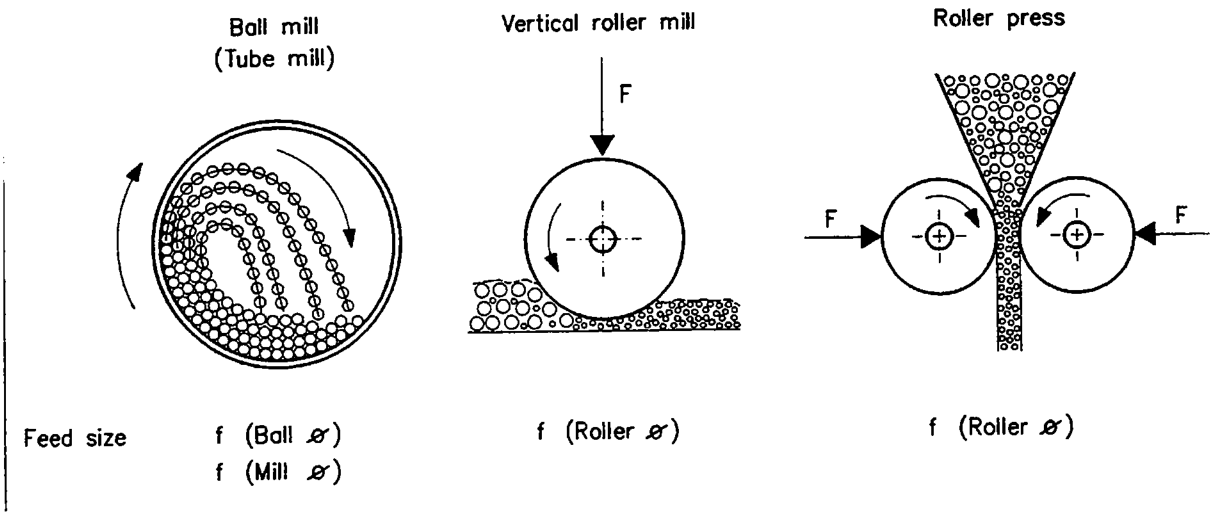
2. RAW MATERIAL PROPERTIES AND PRODUCT QUALITY

- **Raw materials** and correctives used for the raw mix:
  - * Limestone
  - * Marl
  - * Clay
  - * Iron correctives (e.g. iron ore, slag)
  - * Silica correctives (e.g. quartz sand, fly ash)
  - * etc.
- Max. feed size of raw material components to the raw mill depend on the mill type and mill size (figure 2):

Tube mill	< 25 - 50 [mm] (max. ball size!)
Roller mill	< 100 [mm] (max. 5 - 7 [%] of roller diameter)
Roller press	< 50 [mm] (max. 3 - 5 [%] of roller diameter)
Autogenous mill	< 300 [mm]
Hammer/impact Crusher	< 200 [mm]

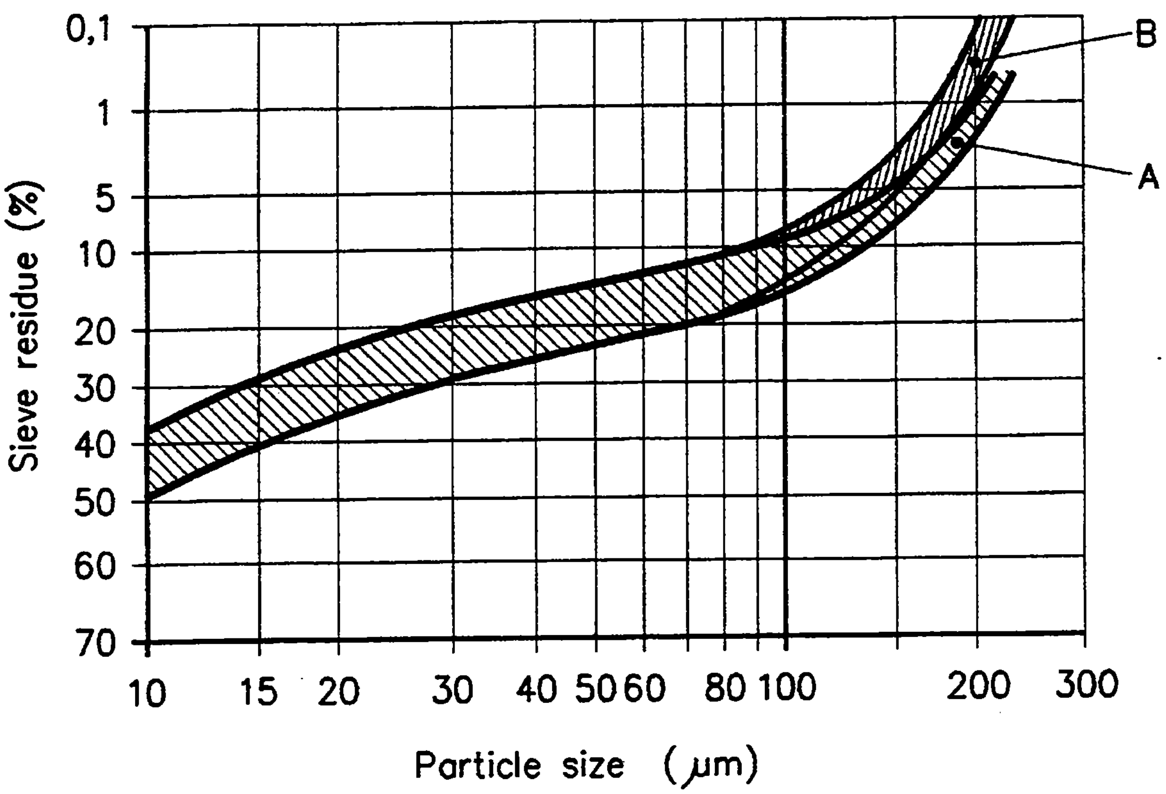
- Besides the max. feed size also the particle size distribution must be observed, and eventually adapted to the needs of the mill type (roller mill, roller press) to enable a stable grinding process.
- The level of raw material moisture limits the application and calls for a certain grinding/drying equipment.
- For high moisture contents (8 - 20 [%] H_20), the drying capacity is the critical item for dimensioning the grinding/drying system.
- For low moisture contents (< 8 [%] H_20), normally the grinding capacity is the predominant factor.
- Indications of moisture contents are always on **wet basis.**
- The stickiness of moist feed components require certain precautional measures for a safe handling such as
  - Bin design
  - Bin extraction facilities
  - Conveyors and chutes
  - Air locks (ev. heated)

Figure 2 Mill Feed Particle Size



- **Product (raw meal)**
  - Raw meal fineness depends on the requirements of burning process and is normally in the range of
    10 - 20 [%] R 90 [µm]
  - The fineness should be determined by the rule
    'Grind only as fine as necessary'
  - Even more important than the residue on 90 [µm] is the one on 200 [µm], as this fraction contains the poor burnable quartz particles. The aim is, to reduce the residue on 200 [µm], while maintaining the same residue on 90 [µm]. The general aim is
    < 0.5 [%] R 200 [µm]
  - A typical range for particle size distribution is shown in figure 3.
- **The raw meal** moisture is usually reduced to < 1.0 [%] H_20, basically to achieve a good flowability and to allow an easy and save handling of the raw meal.

Figure 3 Typical Particle Size Distribution Raw Meal



Ranges of raw meal particle size distribution

A - Conventional
B - Improved (mainly by separator)

Main influence of particle size distribution

⇐ Fine range	Coarse range ⇒
⇐ Grinding process	Design and operation of separator ⇒

3. BASIC RAW GRINDING EQUIPMENT (DRY GRINDING)

3.1 Available Raw Grinding Equipment (figure 4)

Main types:

- Tube mills
  - End-discharge mill
  - Center discharge mill
  - Air swept mill
- Vertical roller mill
- Roller press

Various types:

- Autogenous mill
- Hammer/impact mill

The tube mill is the most used raw grinding equipment up today.

Modern raw grinding equipments are the vertical roller mill for high production and high drying capacities and the roller press for low moisture contents and moderate capacities.

Autogenous and hammer/impact mills are only used for special applications. Autogenous mills are often fitted with a few balls for better efficiency.

Hammer/impact mills are mainly used for pregrinding/predrying purpose, ahead of a conventional tube mill system. They are often used with a kind of flash drier.

In the past, many complicated connections between various grinding/drying equipment have been installed. The trend today goes towards simple and reliable plants.

3.2 Selection Criteria for Raw Grinding Equipment

- Capacity of installation
- New installation or extension
- Moisture content of raw materials
- Raw material hardness (grindability of components)
- Raw material properties (stickiness, abrasiveness, etc.)
- Feed size of raw material (depending on crushing installation)

Figure 4a **Raw Grinding Equipments - Main Types**
Tube Mills

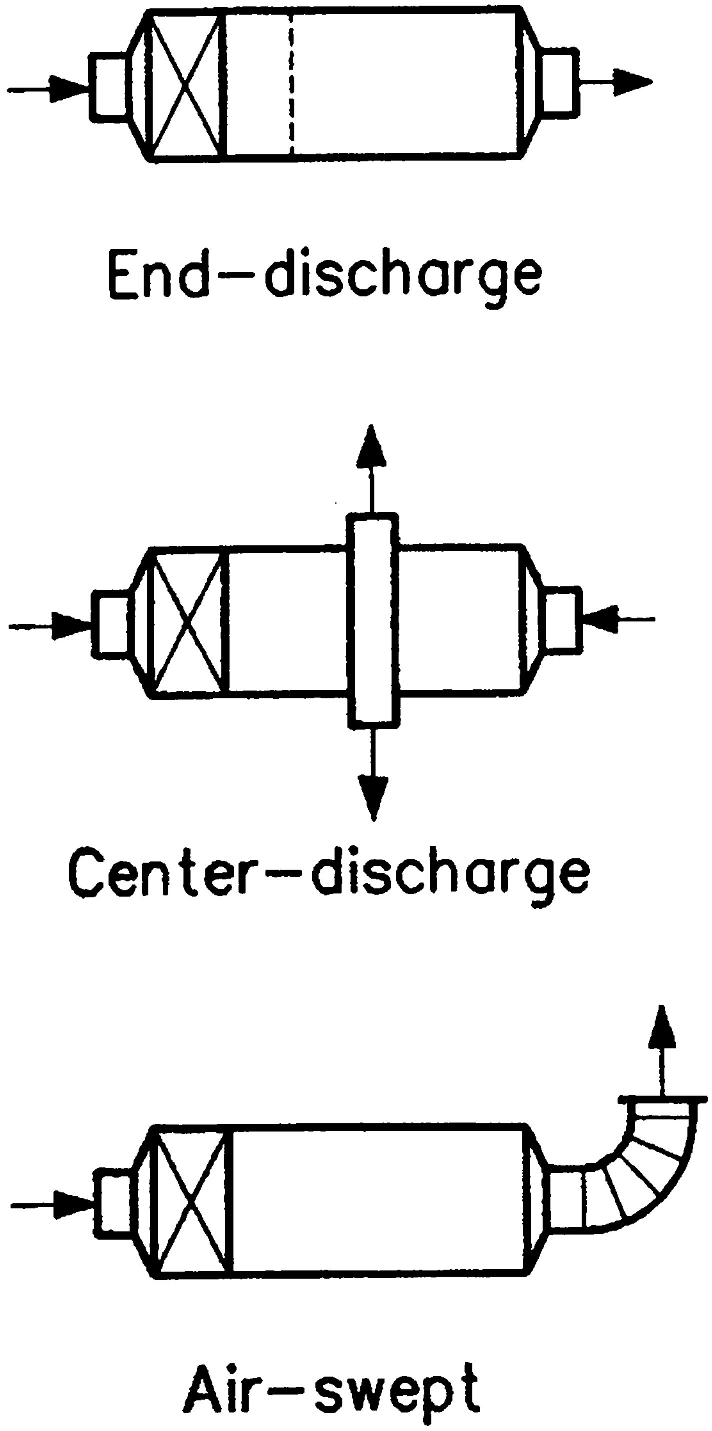


Figure 4b **Raw Grinding Equipments - Main Types**
Vertical Roller Mill

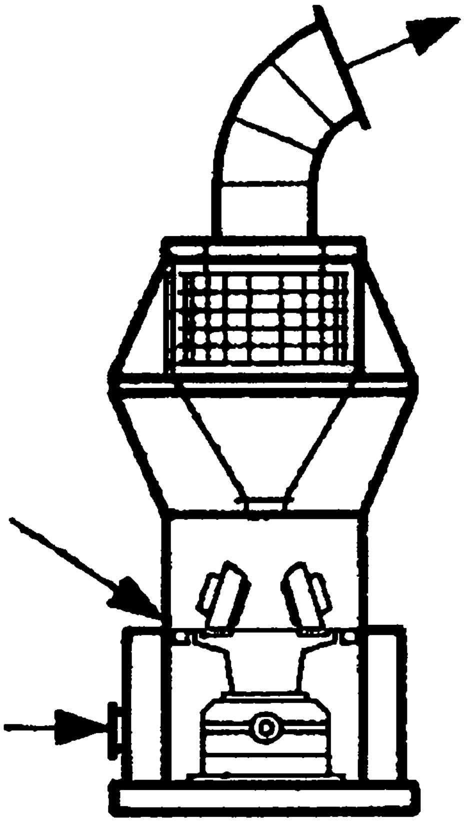


Figure 4c **Raw Grinding Equipments - Main Types**
Roller Press

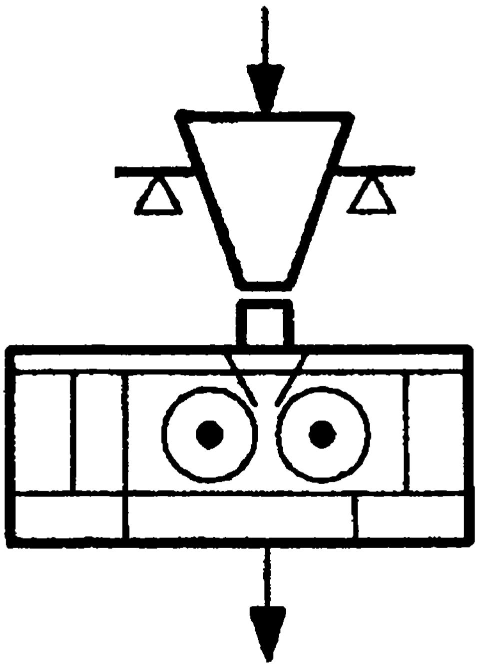
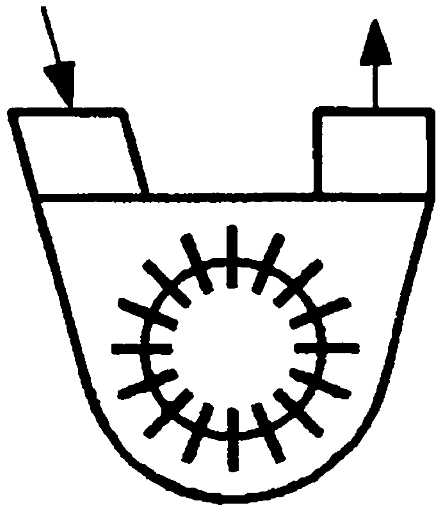
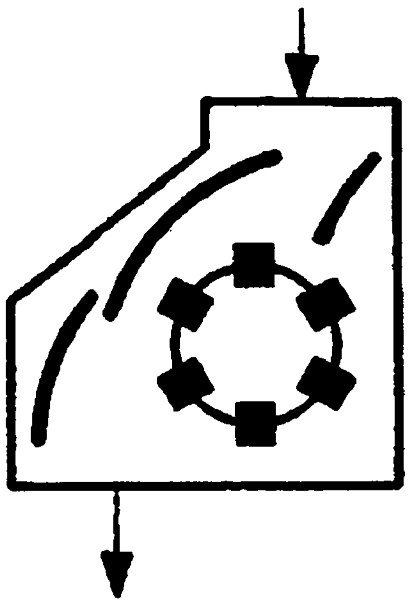


Figure 4d **Raw Grinding Equipments - Various Hammer/Impact Mill**

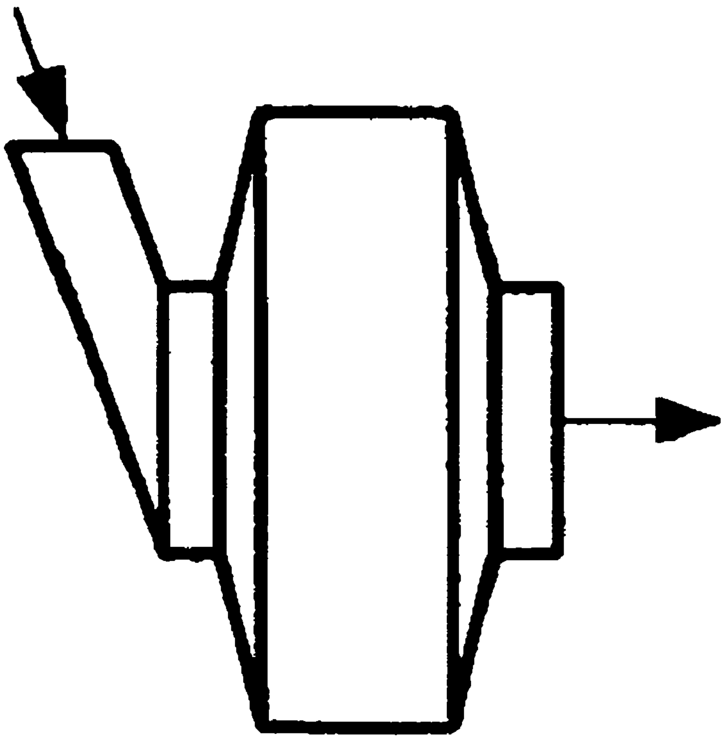


Hammer mill



Impact mill

Figure 4e Raw Grinding Equipments - Various Autogenous Mill



4. DRYING POSSIBILITIES AND PERFORMANCE

4.1 Heat Sources

Kiln exhaust gases (depending on kiln system and number of preheater stages)	< 350 [C]
Cooler exhaust air	< 350 [C]
Hot gas generator	< 600 [C]

Utilizing all kiln exhaust gases, in general, raw material can be dried up to 7 - 8 [%] H_2O. For higher moisture contents, a hot gas generator can be installed. The limitation of drying with kiln exhaust gases is mainly given by the maximum available amount of gases at a production equilibrium between raw mill and kiln. All parts of equipment in contact with hot gases of 450 - 600 [C] have to be lined with refractories and bearings insulated to prevent from overheating.

Max. hot gas temperature for vertical roller mills is < 450 [C] at the mill inlet. The same applies for tube mills without drying compartment.

4.2 Drying Possibilities (figure 5)

- Separate drying (predrying) in
  - Rotary dryers (drum dryers)
  - Dispersion dryers
  - Flash dryers, with or without hammer/impact crusher
- Drying in mills
  - Drying compartments within tube mills or ahead of the tube mills in overhung drying compartments
  - Drying in grinding compartments of tube mills (low drying capacities)
  - Drying in vertical roller mill casing
  - Drying in separator (e.g. for roller presses)

4.3 Drying Performance

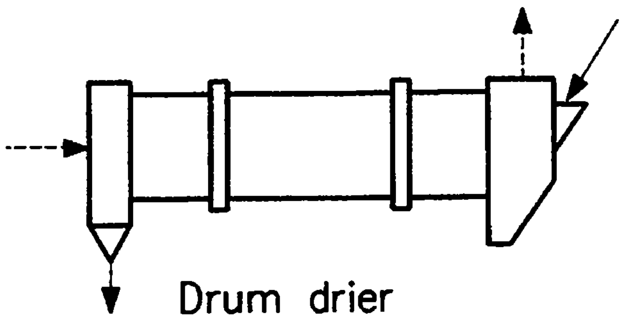
The drying performance depends basically on:

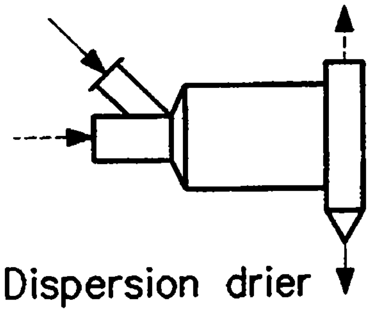
- Type of drying equipment
- Volume and design of drying facility
- Hot gas temperature (energy level)
- Hot gas flow rate (restricted by max. gas speed in drying equipment)
- Raw material properties
- Particle size of material, when drying
- Retention time in drying equipment

Many times, the drying capacity of a given system is limited through the high false air intake in various places of the system, and the installed fan cannot match the entire gas flow rate.

Any drying capacity of mill can be increased by a preceding, separate drying process (e.g. flash drier etc.).

Figure 5a Drying Possibilities - Predrying





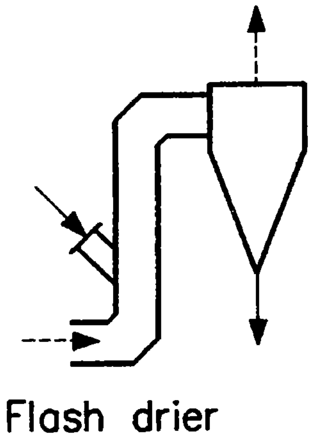
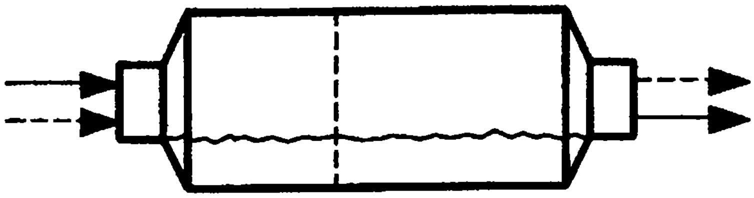
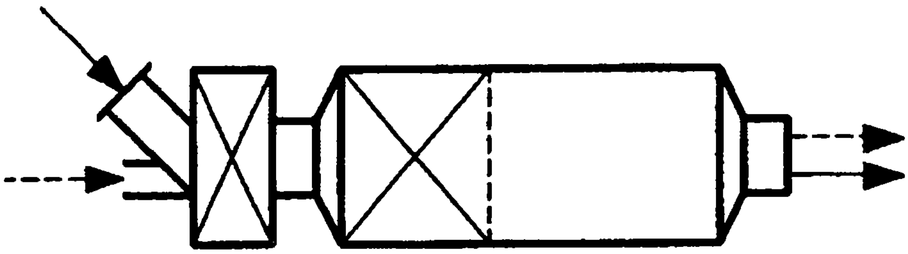


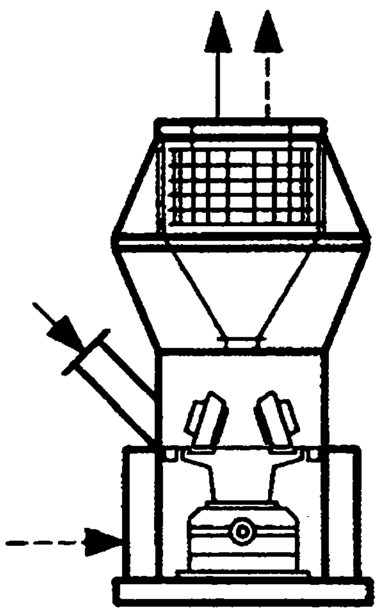
Figure 5b **Drying Possibilities - Drying in Mill**



in Grinding compartment

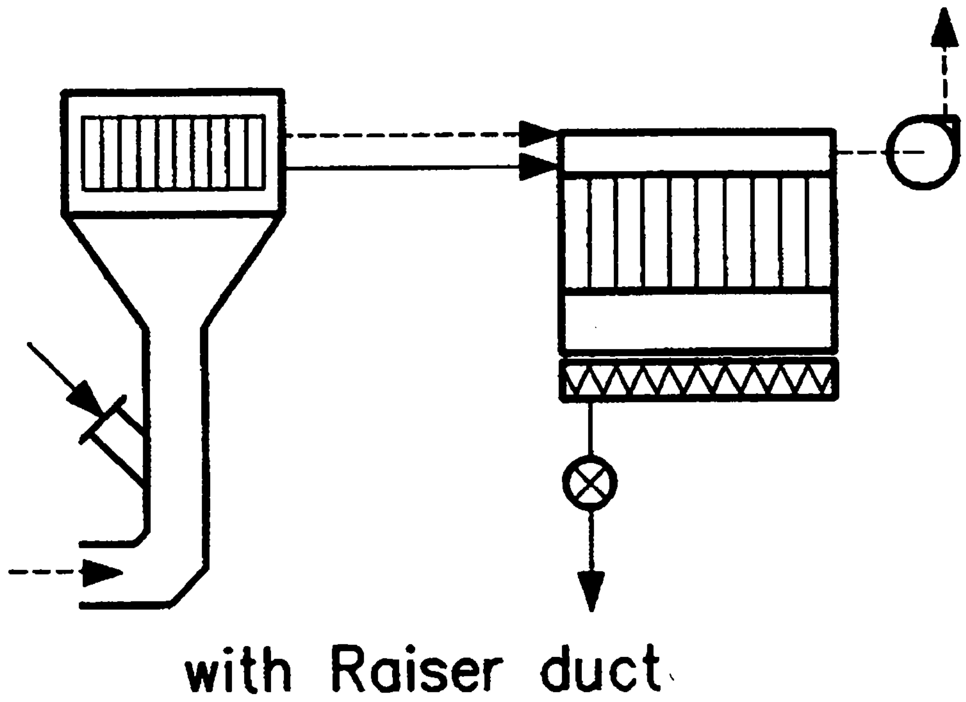


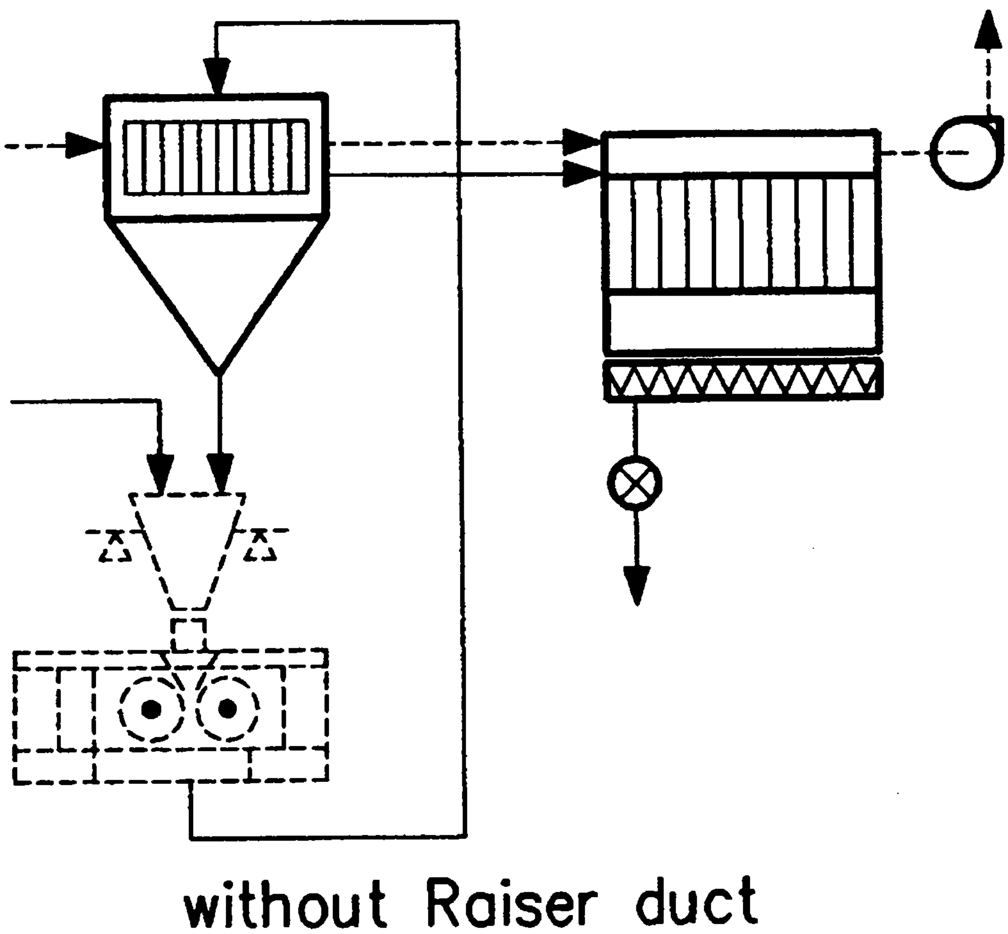
in Drying compartment
(integrated/overhung)



in Roller mill

Figure 5c **Drying Possibilities - Drying in Separator**





5. RAW GRINDING SYSTEMS (DRY GRINDING)

5.1 Raw Grinding System with End-Discharge Mill (Figures 6, 7)

This mill is used for grinding raw materials with low moisture contents or predried materials. The drying capacity is limited by the admissible gas speed through the mill. The drying compartment is either incorporated into the mill shell or as drum installed ahead of the inlet trunnion. The drying gases or the mill ventilating air passes generally through a static separator (4) and is dedusted in a dust collector (5).

The system utilizes a mechanical conveyor (bucket elevator) to lift the mill discharge product to the dynamic separator (3). The mechanical transport is very economical with a minimum of electrical energy consumption.

In some cases, raw material with low moisture content is even dried within the grinding compartment. Moisture contents of 1 - 1.5 [%] can be dried without hot gases. Moisture content s up to 5 [%] can be dried with hot gases. The critical point is to avoid clogging of the intermediate diaphragm with too moist a material.

When drying in the grinding compartment, special care has to be paid to avoid overheating of the grinding media and intermediate diaphragm.

Sufficient cooling and/or insulation of the bearing of tube mills with trunnion bearings has to be provided.

The tube mill may be fitted with one or two grinding compartments, according to the material hardness and feed size.

The mill system is of a conventional, simple and easy operable set-up.

5.1.1 Features

- Low drying capacity (limited by allowable gas speed within the mill < 2 [m/s] over ball charge)
- With or without drying compartment
- With one or two grinding compartments (according to material hardness and consequently adaptation of ball sizes)
- Conventional, simple mill

Figure 6 End Discharge Mill

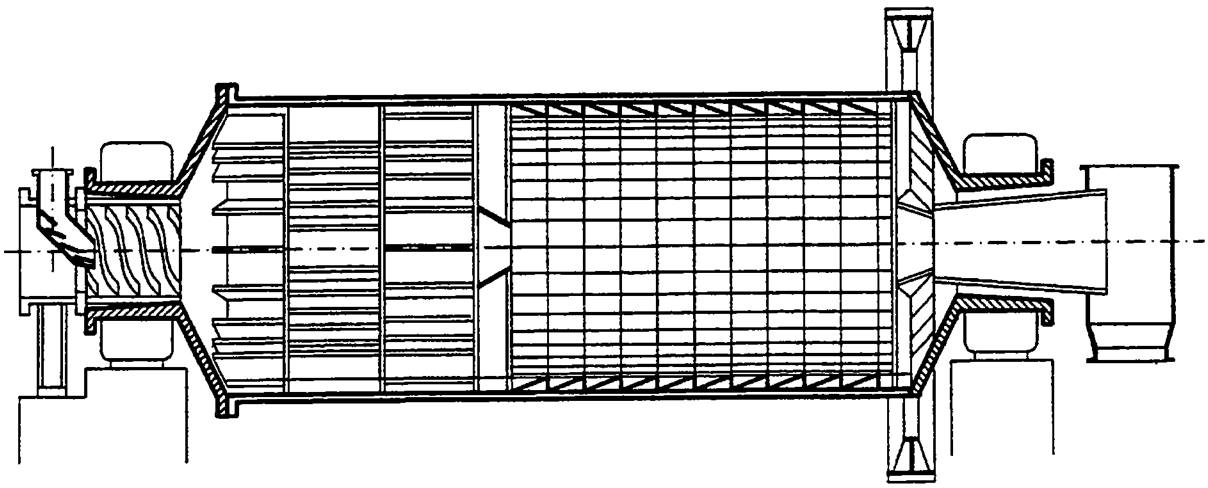
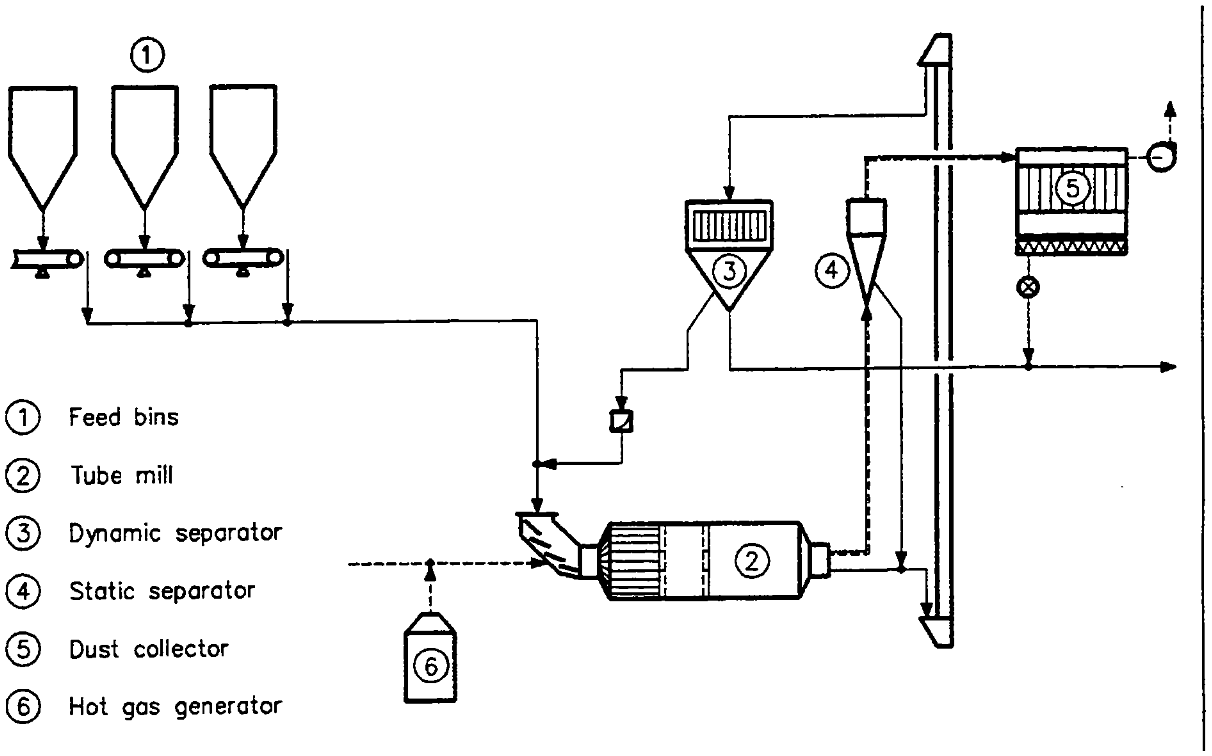


Figure 7 Raw Grinding System with End Discharge Mill



5.2 Raw Grinding System with Center Discharge Mill (Figures 8, 9)

The drying is done in an incorporated drying compartment ahead of the first grinding compartment. For higher moisture contents, also a second drying compartment (drum) ahead of the inlet trunnion is often installed. The drying gases pass the drying and the first grinding compartment before leaving the mill through the central openings around the mill shell. If needed, hot gases can be drawn through the second grinding compartment for a complementary drying or fresh air can be introduced for a normal mill ventilation. The dust in the mill exhaust gases is separated in a static separator (4). The tailings are sent to the dynamic separator whereas the final dedusting of the gases is done in the mill/kiln gas dust collector (5).

The separator tailings from the dynamic separator are fed to the second grinding compartment for fine grinding. Usually approx. 30 [%] of the tailings return to the first grinding compartment.

The center discharge mill is applied for hard grindable raw materials or materials with components of significant different grindabilities. The advantage is, that particles, which are already sufficiently ground after the first compartment, can be classified by the separator and only the harder particles pass through the second compartment.

False air rates are seldom below [%] for mill and mill fan.

As the mills are preferred for harder materials, generally the specific energy consumption of center discharge mill system is higher than for other tube mill systems.

The experience shows, that the center discharge mill system, due to its complexity, is quite difficult to handle and to operate.

5.2.1 Features

- Medium drying capacity up to 15 [%] H_2O with a heat source additional to the kiln exhaust gases
- Suitable for materials of high hardness, and materials with hard and soft components
- Sensitive to false air leakage (sealing around entire mill shell)
- Complex process (difficult distribution of gases and tailings)

Figure 8 Center Discharge Mill

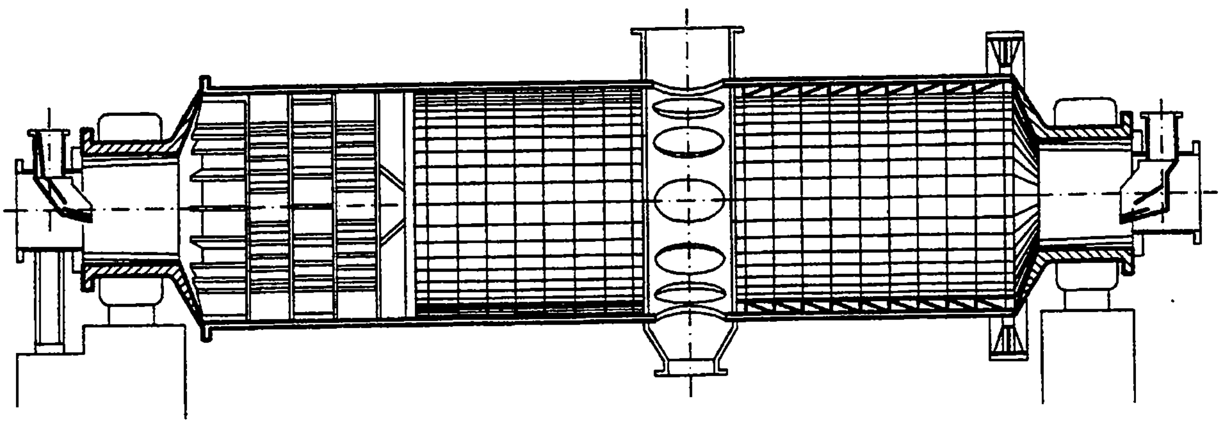
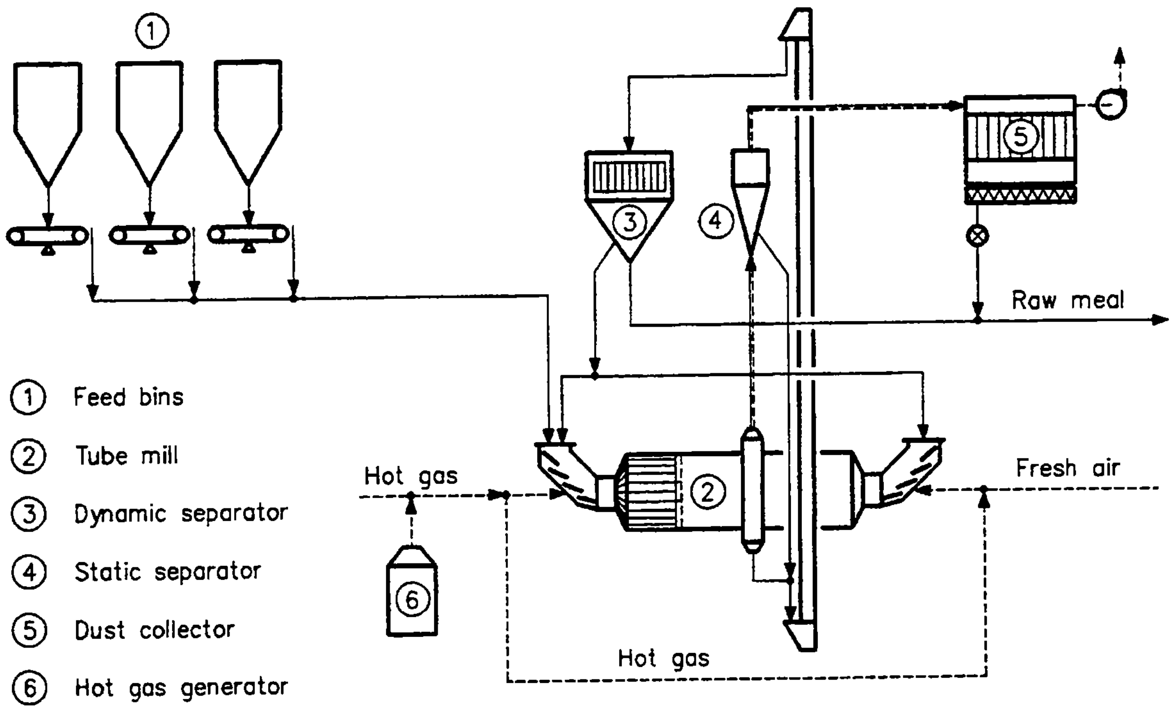


Figure 9 Raw Grinding System with Center Discharge Mill



5.3 Raw Grinding System with Air Swept Mill (Figures 10, 11)

Drying, grinding and transport are close connected in an air swept mill system. The drying is done in an incorporated drying compartment, the grinding in a subsequent single grinding compartment.

The single grinding compartment requires a corresponding pattern of liner plates, as the materials have to be ground from feed size down to the final fineness in this compartment. Often lifting or combi liners are used over the first few meters of the compartment and classifying or combi liners over the rest of the compartment.

One of the weak points of the air swept mill is the diaphragm between drying and grinding compartment, which has to provide low pressure drop for the gas flow and a good passage for the feed materials.

The drying gases discharge the ground materials from the grinding compartment and convey the materials through a static or dynamic separator (3) to a dust collection facility (4) (5). The grits from the separator return to the mill inlet.

One part of the mill exhaust gases are recirculated form the mill fan outlet to the mill discharge to ensure a sufficient gas speed for the material transport. An other part of the gases are recirculated to the mill inlet to maintain a proper gas speed and constant conditions within the mill. Excessive false air presents often a capacity problem of the mill fan and makes a proper control difficult. False air rates of more than 25 [%] over mill and fan are common.

The close connection between drying and transport with the hot gases make the system quite difficult for a proper adjustment and optimization.

The pneumatical transport leads to higher electrical energy consumption for the transport part.

5.3.1 Features

- Medium drying capacity (limited by max. gas speed within the mill < 6 [m/s])
- Low to medium hardness of materials (single grinding compartment)
- Small feed size to mill required (< 30 [mm])
- Difficult adjustment of the ball charge distribution
- Higher gas flow rates cause higher circulating loads

Figure 10 Air Swept Mill

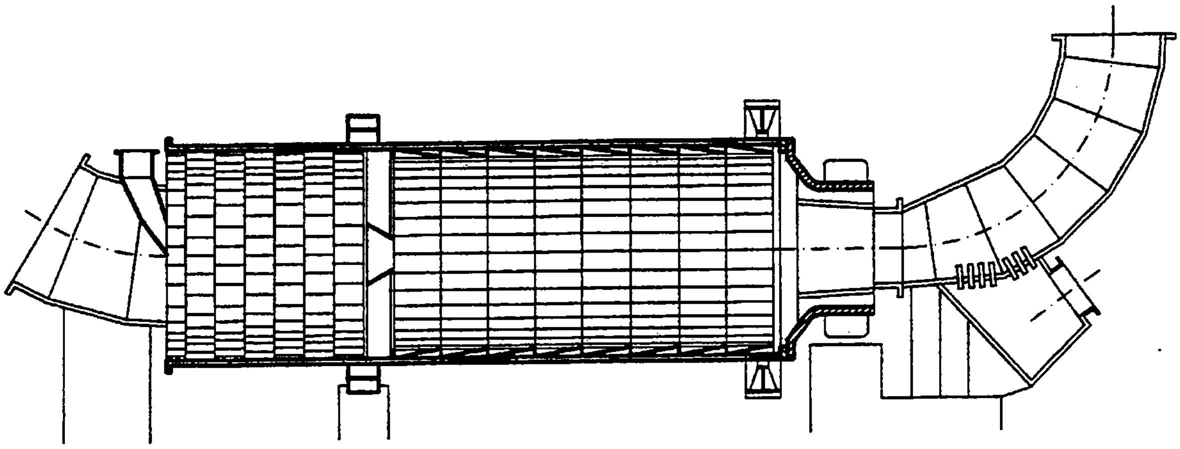
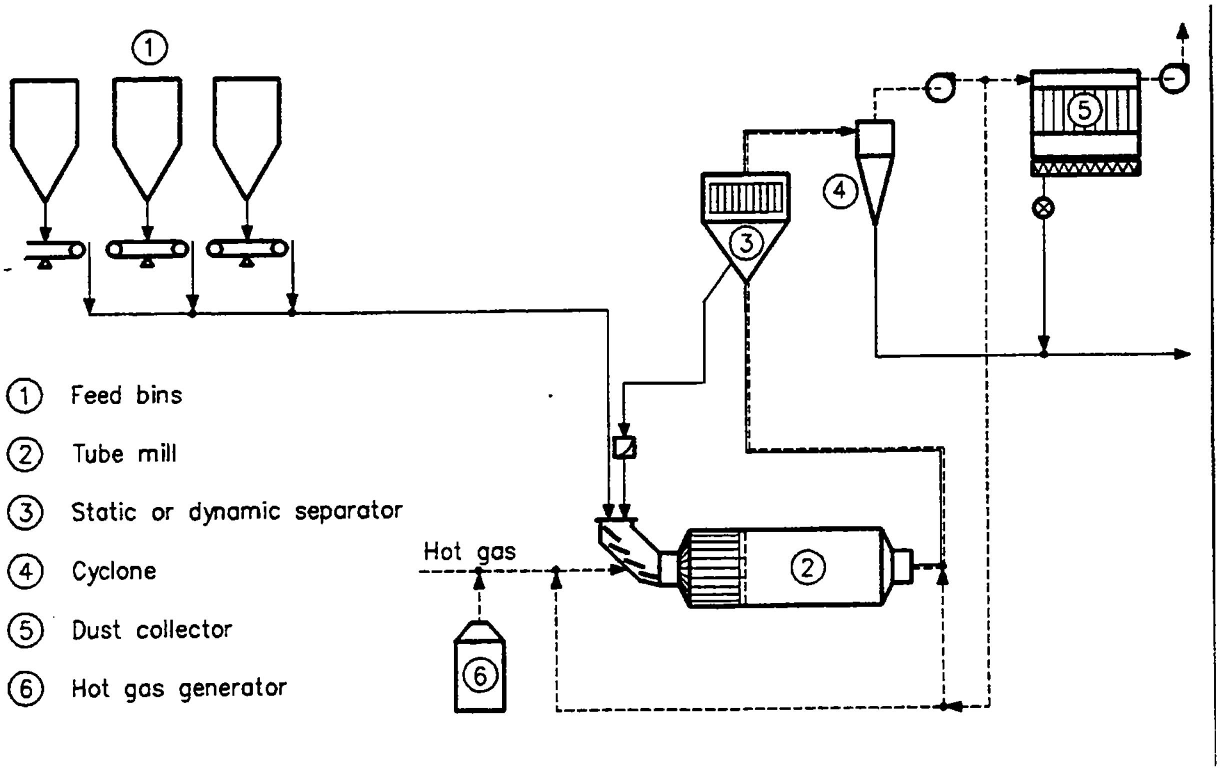


Figure 11 Raw Grinding System with Air Swept Mill



5.4 Raw Grinding System with Vertical Roller Mill (Figures 12, 13)

Drying, grinding and separating are done in one single machine.

The drying gases are used to dry, to provide the internal material circulation, the transport to and from the separator as well as acting as separating air. The system can only be kept in equilibrium and in stable conditions by controlling and maintaining a constant gas flow through the roller mill. Normally recirculating gases are used to maintain the gas flow constant and a negative pressure at the mill inlet. The drop of the gas pressure across the mill is usually kept constant by adjustment of mill feed rate.

Some systems are setup with cyclones and three fans, whereas others operate only with a filter (3) and two fans. The duct for the gas recirculation and the duct for direct operation of kiln gases to the filter should always be separate to avoid operating problems.

This roller mill system works with high negative gas pressures and needs therefore special care of the sealings to avoid excess false air intake. False air rates of more than 20 [%] over mill and fan are common.

The external material circulation with a bucket elevator (4) is used to recirculate coarse material, which falls through the nozzle ring back to the mill inlet. The bucket elevator can easily be used with a surge hopper in connection with a metal detector by-pass or when emptying the mill for maintenance purpose.

For low moisture the mill is sized according to the grinding capacity, and for high moisture according to the necessary gas flow rate (casing diameter).

5.4.1 Features

- High drying capacities, up to 20 [%] with an additional hot gas generator
- Max. mill inlet temperature of < 450 [C] admitted
- Efficient grinding process in a compact machine
- More specialized maintenance staff required
- Coarse material feed size possible < 100 [mm]
- Operation at partial load 70 - 100 [%] possible
- Large grinding capacities up to approx. 550 [t/h] in one machine

Figure 12 Vertical Roller Mill

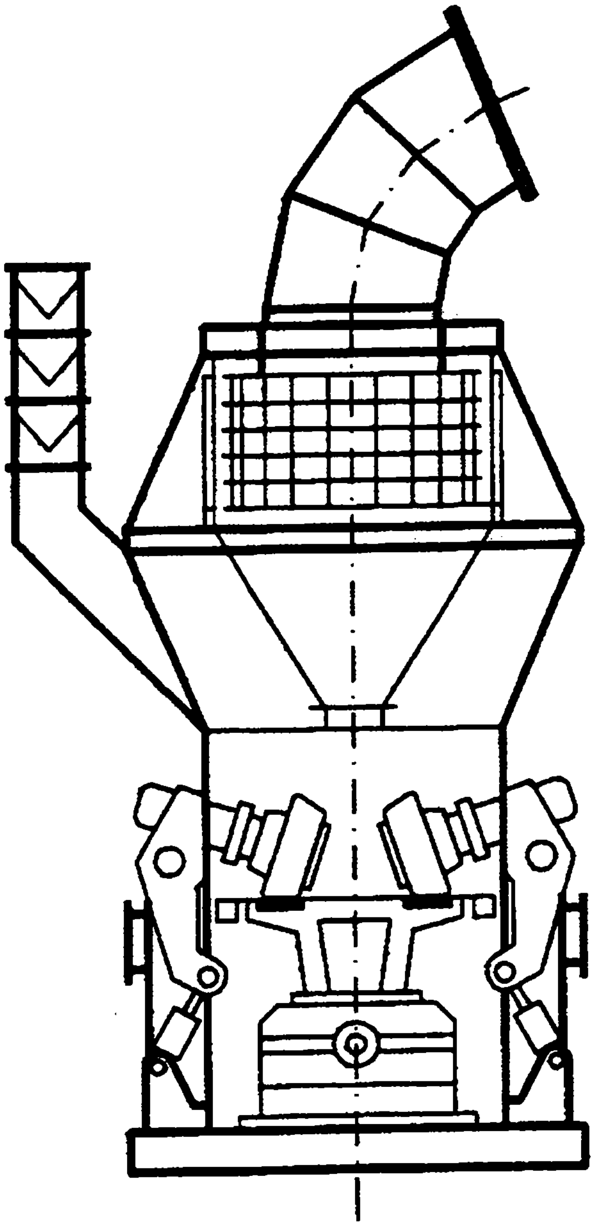
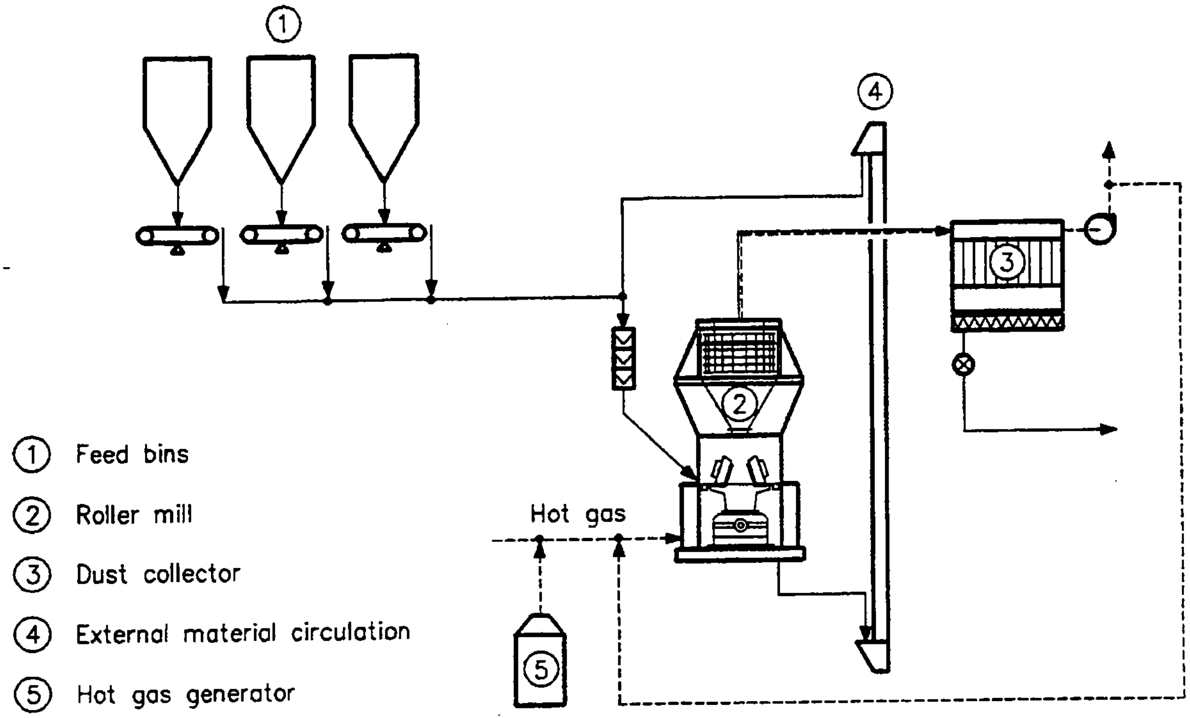


Figure 13 Raw Grinding System with Vertical Roller Mill



5.5 Raw Grinding System with Roller Press (Figures 14, 15)

The materials are proportioned to a press feed hopper and are dosed to the gap between the rolls of the press (2). The discharge material from the press consists of slabs, a type of compacted flakes. The slabs contain a portion of fine material which has to be broken up in a desagglomerator (3) before it can be fed to the separator (4). The fines from the separator are collected in a dust collector (5) and leave the system as raw meal. The separator tailings are sent back to the roller press.

The entire drying takes place in the separator where hot gases are utilized for drying and separating. The maximum hot gas temperature at the separator inlet depends on the placement of the rotor bearing and its maximum admissible operating temperature and will generally be around 250 - 300 [C].

For higher drying capacities a single pass separator (4) (5), where up to 100 [%] of the separating air can consist of hot gases, may be used. For lower drying needs a cyclone air separator (4a) with a steady use of high amounts of recirculating gases is recommended.

A possibility for drying higher moisture contents is the use of a vertical duct under the separator, which acts as a flash drier (figure 5). In this case, the bucket elevator is replaced by the raiser duct, feeding the separator with the material laden flow of hot gas from below. Fine and moist correctives can be fed directly to the raiser duct.

Material moisture is limited to 3 - 5 [%] H_20, above this, the grinding efficiency is reduced and a predrying facility will be necessary. The drying will be completed in the separator.

Fine and dry feed components call for a reduction of the roller speed for vibration free operation, resulting in lower production rates.

5.5.1 Features

- Suited for low moisture of feed material or even predried materials
- Moist components reduce the grinding efficiency and increase the wear rates of the rolls surface
- Feed components with high quartz contents also provoke high wear rates, which may cause excessive stops for rolls surface recharching
- Moist feed components may present flow problems in the press hopper
- Feed size limited to < 50 [mm] (draw-in action to roller gap!)
- Size of a single machine system up to 200 [t/h]

Figure 14 Roller Press

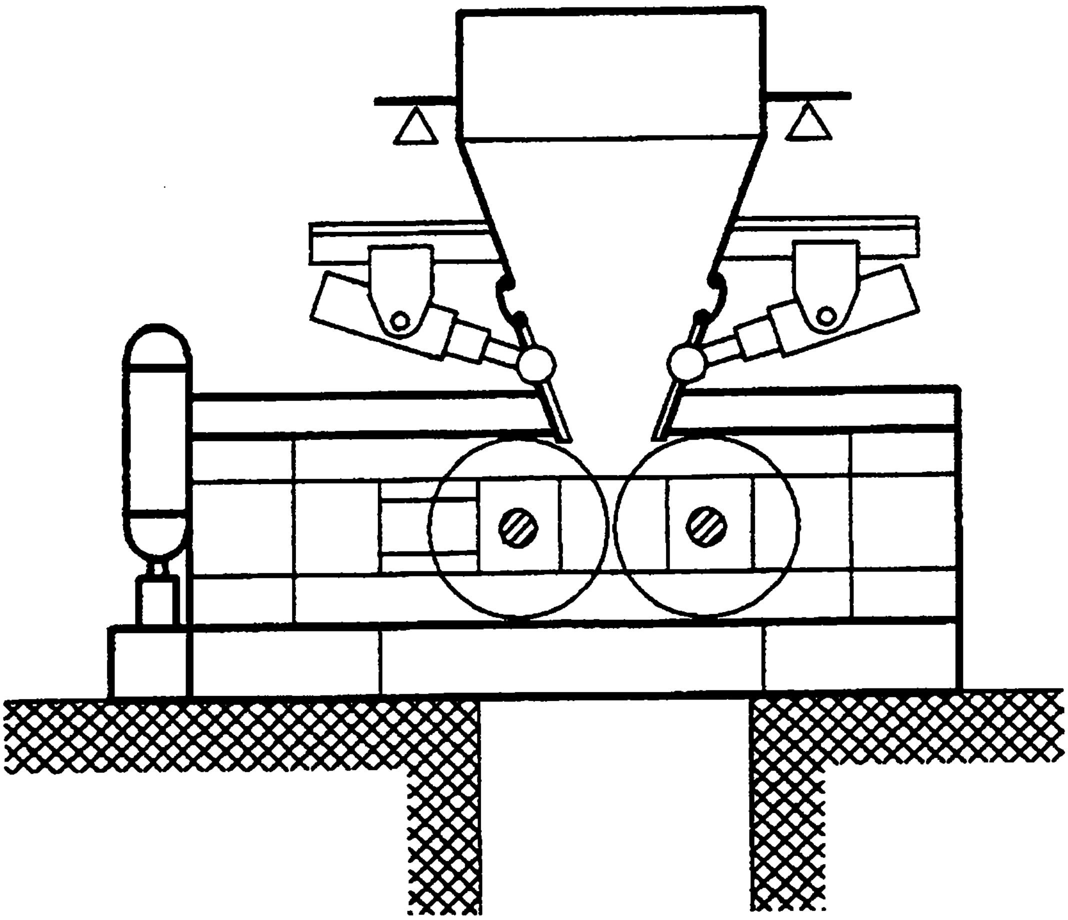
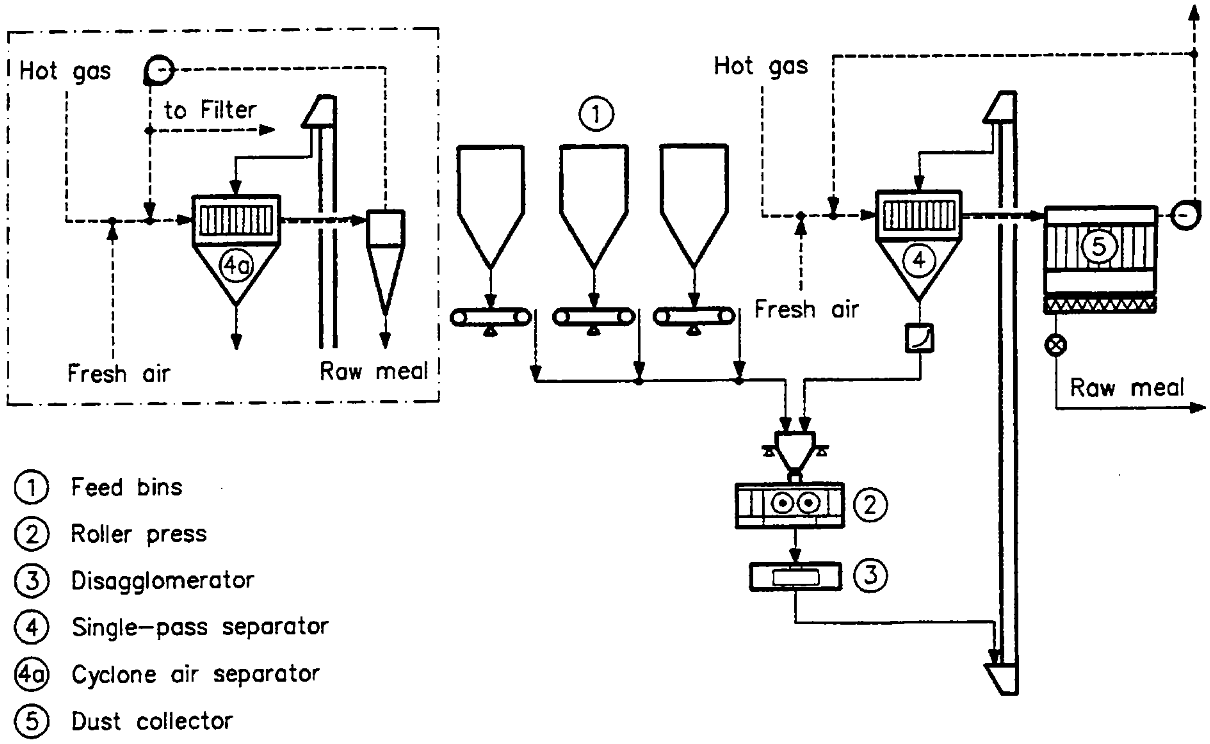


Figure 15 Raw Grinding System with Roller Press



6. WET GRINDING (FIGURES 16, 17)

The wet grinding is an older process which, today and in the future will no more be installed, provided very special conditions are prevailing.

Typical mills for wet grinding are tube mills with balls or rods.

The raw material is fed through a spout feeder to the tube mill with addition of water. The product leaving the mill is a slurry which is pumped (3) to a slurry basin (5). The slurry is further conveyed to a wet kiln or treated by a filter press. In case of a filter press, the filter cakes are either granulated and fed onto a traveling grate or dried in a drier before being fed to a semi-wet process kiln.

Slurries have typical moisture contents of 28 + 42 [%] H_2O.

A typical water content of cakes after the filter press is approx. 15 - 18 [%] H_2O.

Due to the high water content in the mill, high wear rates (mainly corrosion) at liners and grinding media are resulting. The mills must frequently be recharged with grinding media.

The slurry mills are either operated as open circuit or as closed circuit mill systems. In the latter case, DSM screens (4), centrifugal or vibrating screens, or hydrocyclones are utilized for separation of the fine and the coarse fraction.

The electrical energy consumption of a slurry tube mill is quite low as the water addition to the mill favors the grinding. However more thermal energy is necessary for drying of the high water contents of the slurry.

6.1.1 Features

- Suited for wet raw materials, escavated from under water
- Low electrical grinding energy needed
- Heavy wear of mill internals and pumps
- Today only used in special cases

Figure 16 Slurry Mill

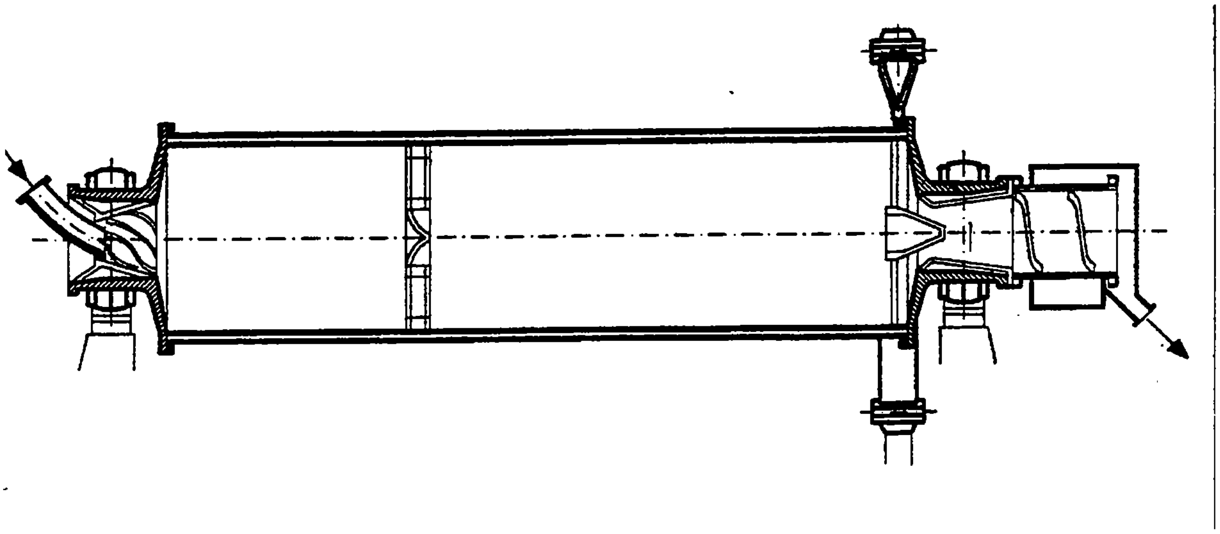
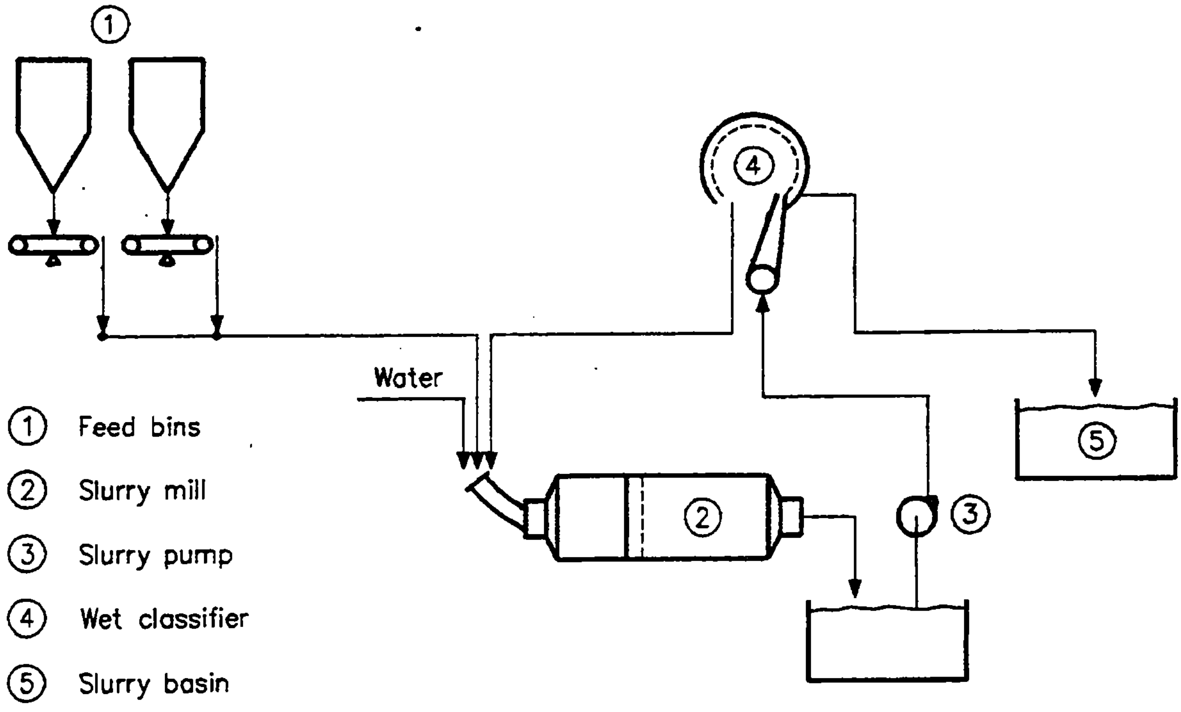


Figure 17 Wet Grinding System with Wet Classifier



7. COMPARISON OF RAW GRINDING SYSTEMS

7.1 Performance (Figure 18)

- **Moisture content:** The moisture content of raw material is the predominant criteria for the performance of a raw grinding/drying system. The drying capacity is limited by the max. allowable gas speed within the drier/mill, the volume of drying compartment and the available amount and temperature of hot gases.
- **Material feed size**: Materials fed to a specific grinding facility have to be crushed to the suitable max. particle size. In tube mills, the max. ball diameter can be adapted in a very small range to cope better with a specific feed size.
- **Grinding capacity**: The grinding capacity of a tube mill system increases with smaller material feed size. The finer the raw meal, the lower the production rate.
- **Stickiness**: Sticky components are difficult to handle and have to be put into a drying compartment before grinding (roller press is not suitable).
- **Abrasivity:** Suitable equipments are those which have easy replaceable and cheap wear parts (tube mills).

7.2 Energy Consumption (Figures 19, 20)

- **Grindability**: Raw material grindabilities vary in wide range according to the specific properties of the components. A comparison between various raw grinding systems can only be done on basis of grindability tests.

  Among the tube mill systems, the slurry mills are generally the lowest (due to the water addition) and the center discharge mills the highest (suitable system for hard materials) in electrical energy consumption.
- **Specific energy consumption**: Generally can be said, that the lowest specific energy consumption can be achieved with roller mill and roller press systems based on the more efficient grinding principle.
- The experience shows, that three fan systems have about the same specific energy consumption as two fan systems.

7.3 Grinding Installation

- **Complexity**: Complex systems like center discharge and air swept mill systems are often difficult to optimize, as there are many interactions between various parameters. The same applies to systems with integrated pregrinding/predrying facilities.
- **Extensions:** Often the grinding capacity of an existing tube mill system can be increased by adding a pregrinder, but the drying capacity can only be increased with higher efforts in costs and considerable space requirements.

Figure 18 Performance of Raw Grinding Systems

FIG.18 PERFORMANCE OF RAW GRINDING SYSTEMS

Type of Mill	Drying Capacity [%] H2O (5, 10, 15, 20)	Max. Mill Feed Size [mm]	Max. Mill Gas Speed [m/s]	Max. Mill Capacities [t/h]	Energy Consumption	Stickyness of Materials	Maintenance
End-Discharge Mill		25-30	2	350	medium	no	simple
Center-Discharge Mill		30-50	2	350	high	suited	simple
Air-Swept Mill		25-30	6	350	medium	suited	simple
Vertical Roller Mill		100		550	low	suited	specialized
Roller Press		50		200	low	no	specialized
Hammer/Impact Mill		200		100	medium	no	medium
Autogenous Mill		300		400	high	very suited	simple

Legend:
- (dotted box) without drying compartment
- (white box) with gases of max. 350 [C] (kiln exhaust gases)
- (black box) with gases of more than 350 [C] (hot gas generator)

--> Higher drying capacities can be achieved with predrying facilities (e.g. flash drier etc.)

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Figure 19 Spec. Energy Tube Mills

("HOLDERBANK" PLANTS 1991)

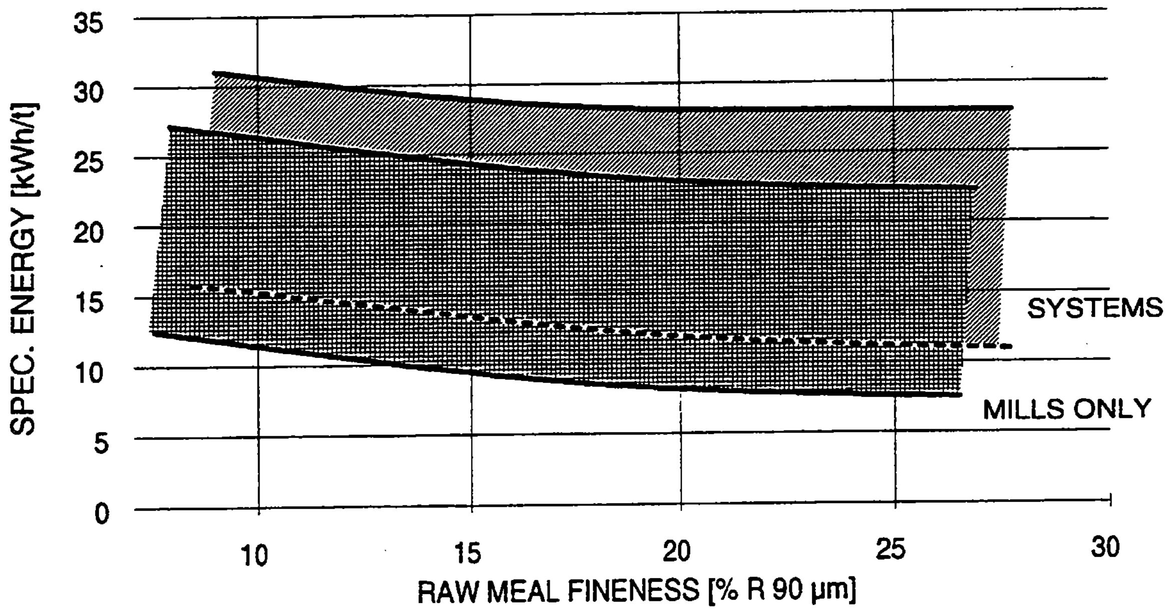

Figure 20 **Spec. Energy Roller Mills**